Istituto Nazionale di Geofisica e Vulcanologia

Can geodetic strain rate be useful in seismic hazard studies ?

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GRUPPO NAZIONALE DI GEOFISICA DELLA TERRA SOLIDA

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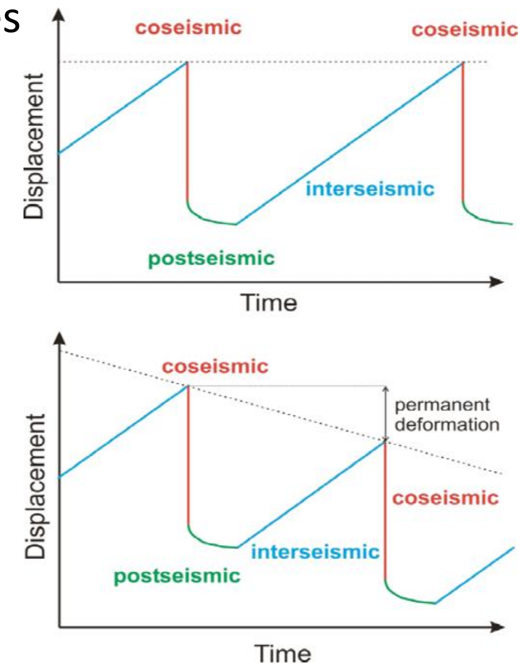
Basic points

- Geodetic Strain-Rate measures how fast the lithosphere is deformed due to tectonic plate motion
- In some places, the crust is brittle enough to produce earthquakes by faulting
- When earthquakes occur they release the accumulated crustal strain

Theoretical time series



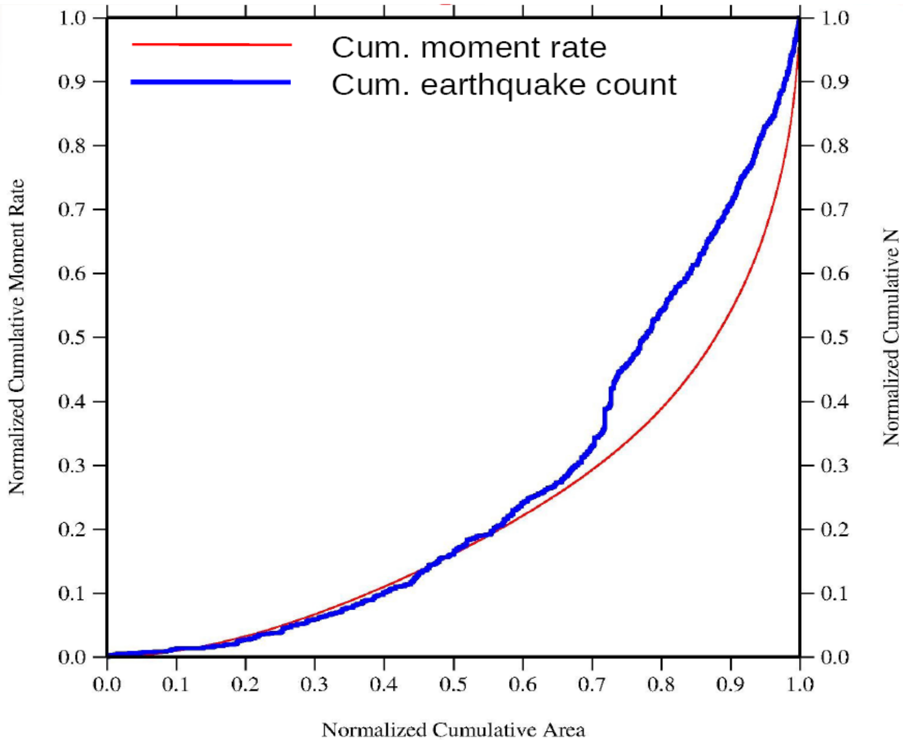
Strain-Rate

can be considered as a proxy for

earthquake potential

Current view

Measured geodetic strain rate is compared to the earthquake activity rate to assess unbalances and provide insights for future seismic activity



GEM
http://www.globalquakemodel.org/what/seismic-hazard/strain-rate-model/

- conceived for long-term assessment of earthquake occurrence

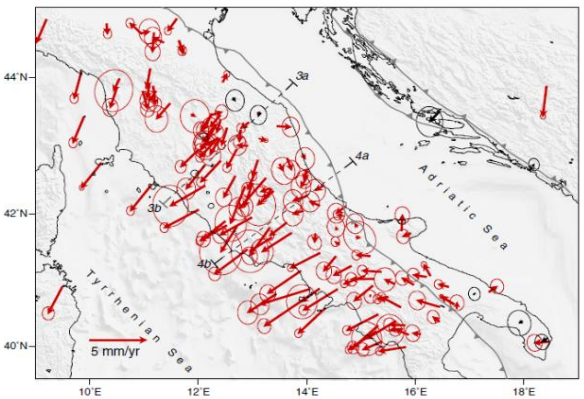
so that

- comparison on limited areas cannot account all the strain rate loaded by plate motion
- comparison on a limited time span implicitly assumes a linear time evolution of loading rate

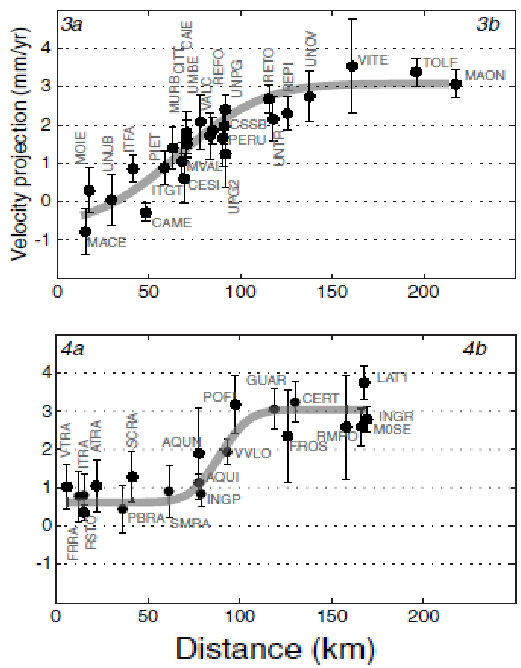
Our view

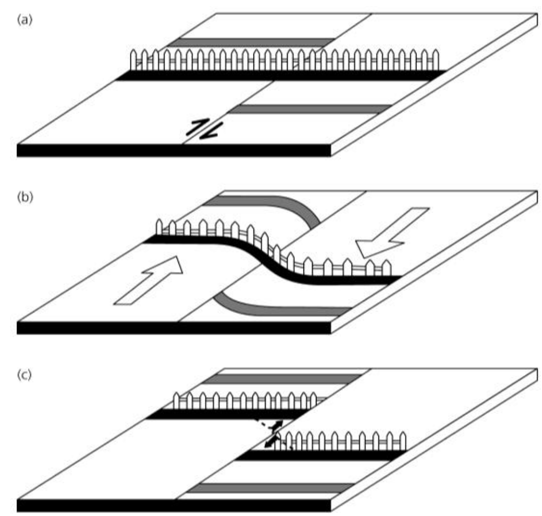
strain rate must be considered space and time dependent

- strain is built up by plate interactions and is released on faults during the seismic cycle
- in the pre-seismic phase, faults are mostly locked
- strain is maximum when the fault is "ripe", wheras strain-rate is minimum



Devoti et al., 2011

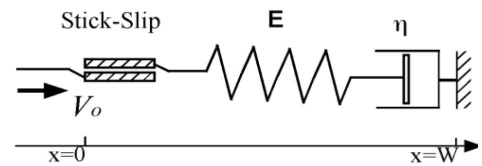


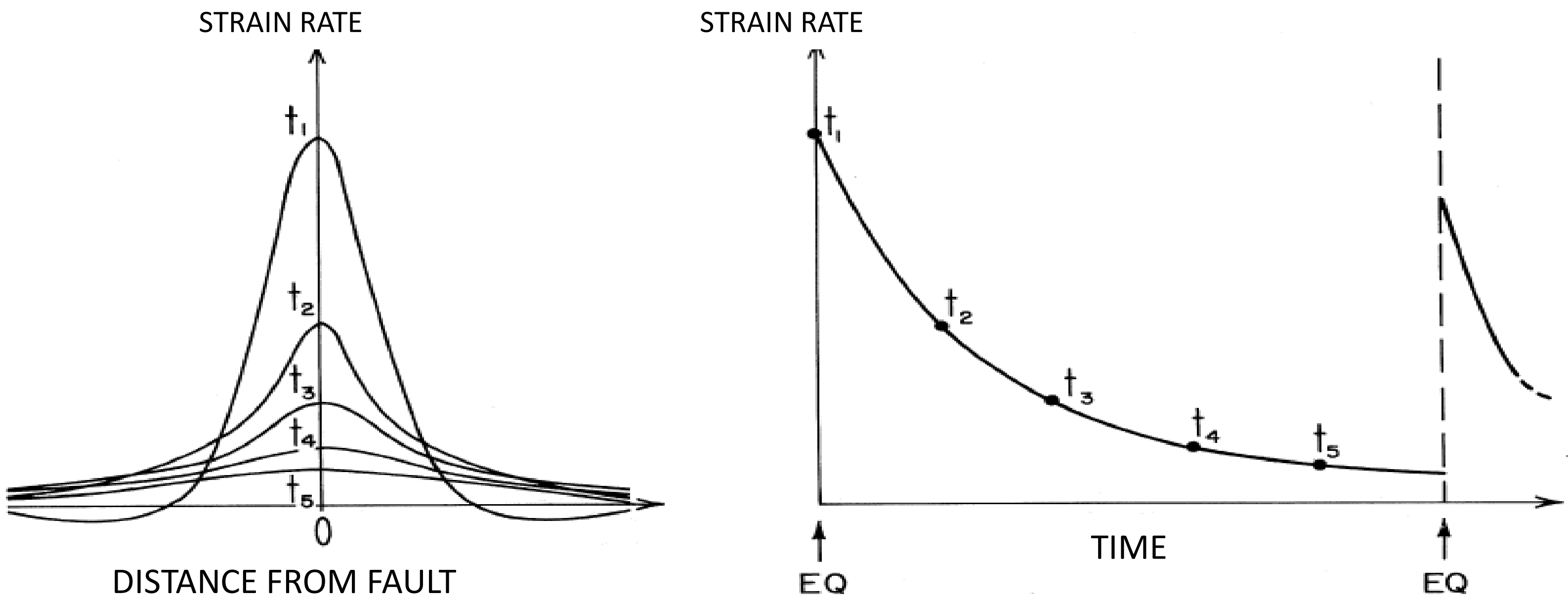


Our model

Idealized seismic cycle ⟺ history of strain rate near faults

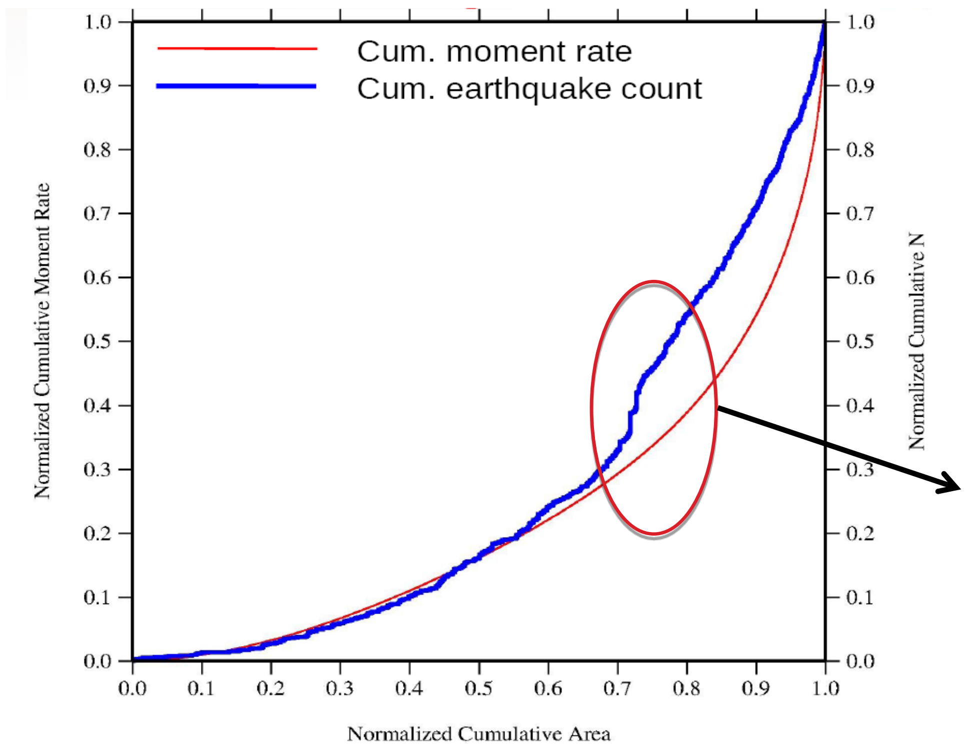
- the tectonic load acts at large scale far from faults
- the strain-rate near active faults is non-linear in time
- the fault is "ripe" when the strain-rate is at minimum
- the slow accumulation of elastic strain ⟺ frictional locking of the fault between eqs





Thatcher, 1993

Average vs. instantaneous deformation rate



GEM
http://www.globalquakemodel.org/what/seismic-hazard/strain-rate-model/

Geodetic deformation rate is compared to the earthquake activity rate to assess imbalances and provide insights for future seismic activity

Seismic / geodetic imbalance may be caused by localized non linear strain accumulation

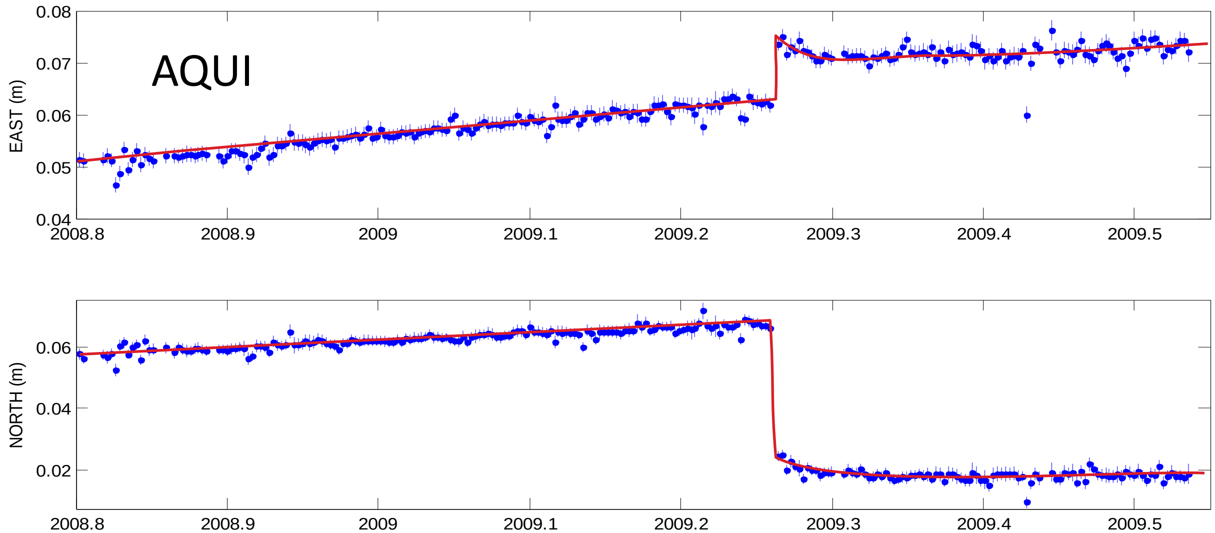
Our Background : GPS observations

Time series of GPS coordinates sample the seismic cycle at each station

Interseismic: linear displacement as a function of time => constant velocity.

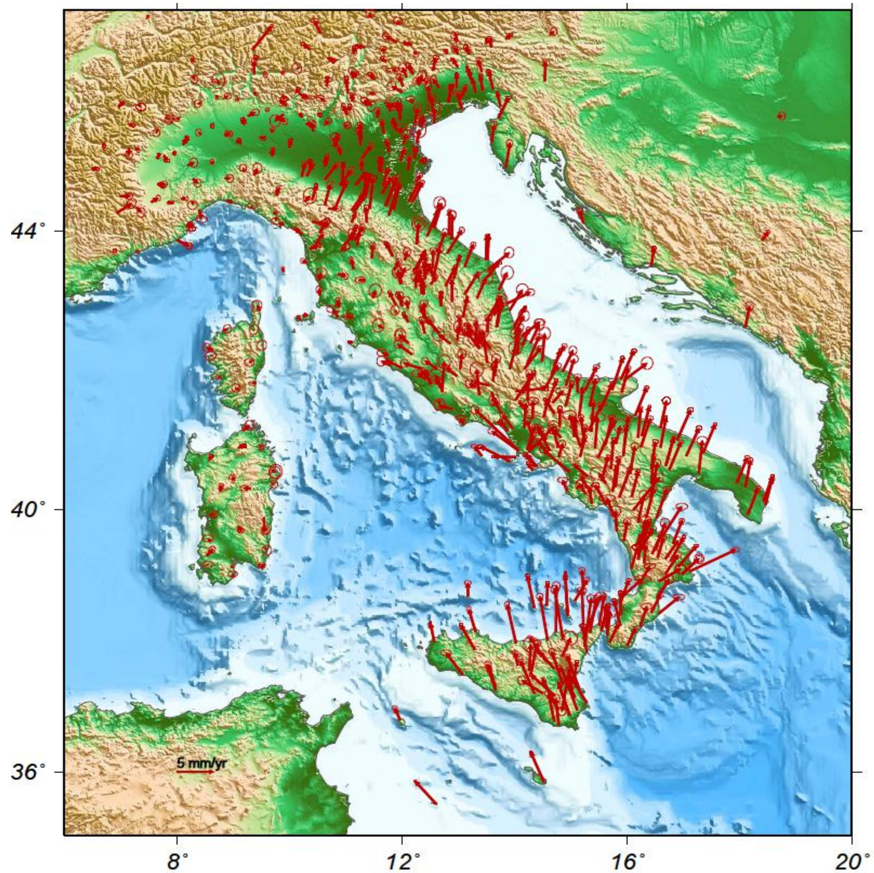
Coseismic: offset of the GPS time series, related to the magnitude and depth of the seismic rupture

Postseismic: strain readjustments (afterslip, viscoelastic relaxation, poroelasticity), decay related to the mechanism and the lithospheric rheology



1a- Mapping the strain rate: a snapshot of an evolving deformation field

geodetic strain rate = spatial gradient of a sparse velocity field



$$\begin{pmatrix} \dot{\varepsilon}_{11} & \dot{\varepsilon}_{12} \\ \dot{\varepsilon}_{21} & \dot{\varepsilon}_{22} \end{pmatrix} = \begin{pmatrix} \dfrac{\partial v_x}{\partial x} & \dfrac{1}{2}\left(\dfrac{\partial v_x}{\partial y} + \dfrac{\partial v_y}{\partial x}\right) \\ \dfrac{1}{2}\left(\dfrac{\partial v_x}{\partial y} + \dfrac{\partial v_y}{\partial x}\right) & \dfrac{\partial v_y}{\partial y} \end{pmatrix}$$

2D strain rate tensor

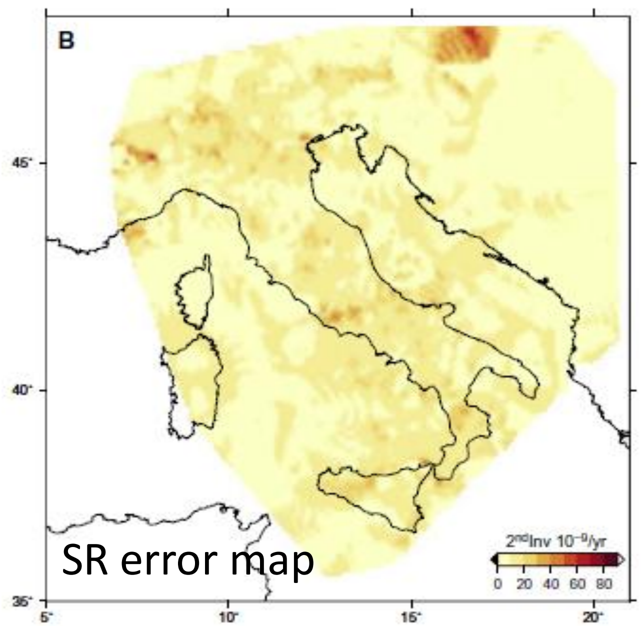
Devoti et al., 2011

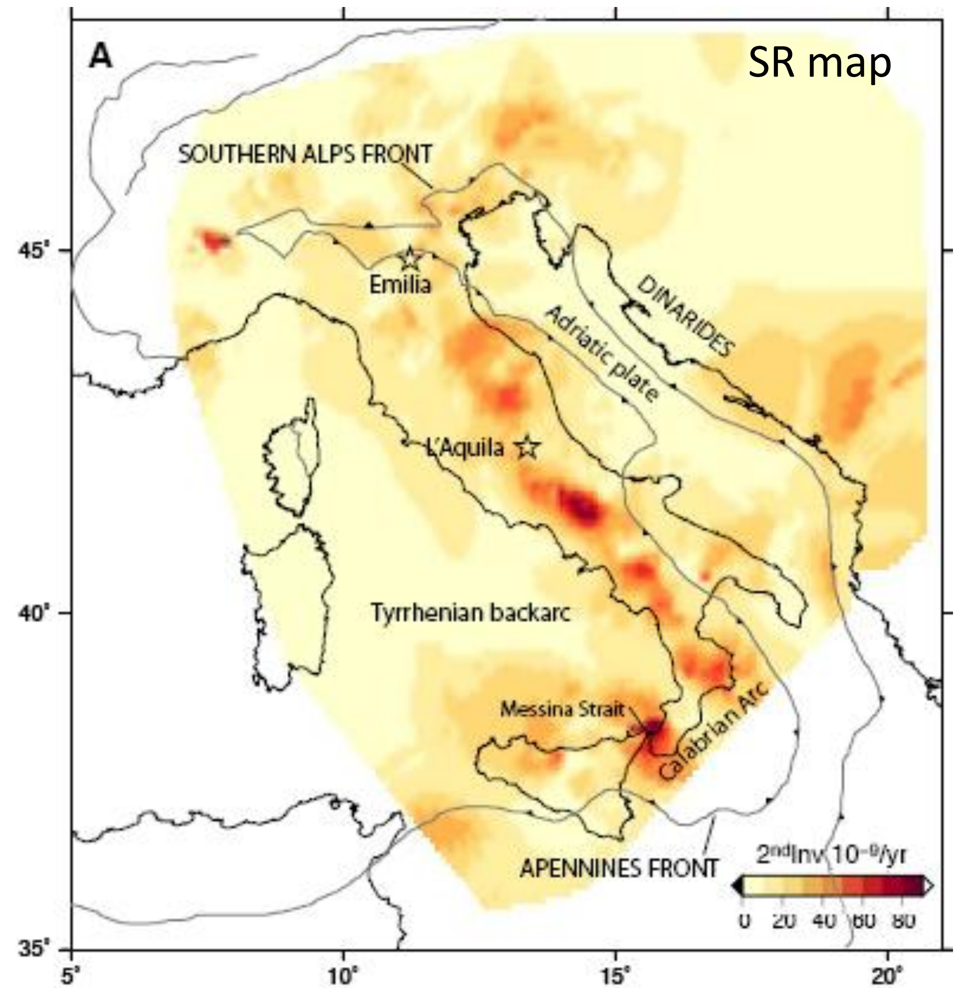
1b- Mapping the strain rate: a snapshot of an evolving deformation field

SR = total strain-rate
sum of all the 2D tensor components

- velocity interpolation on a regular grid
- smoothing with distance

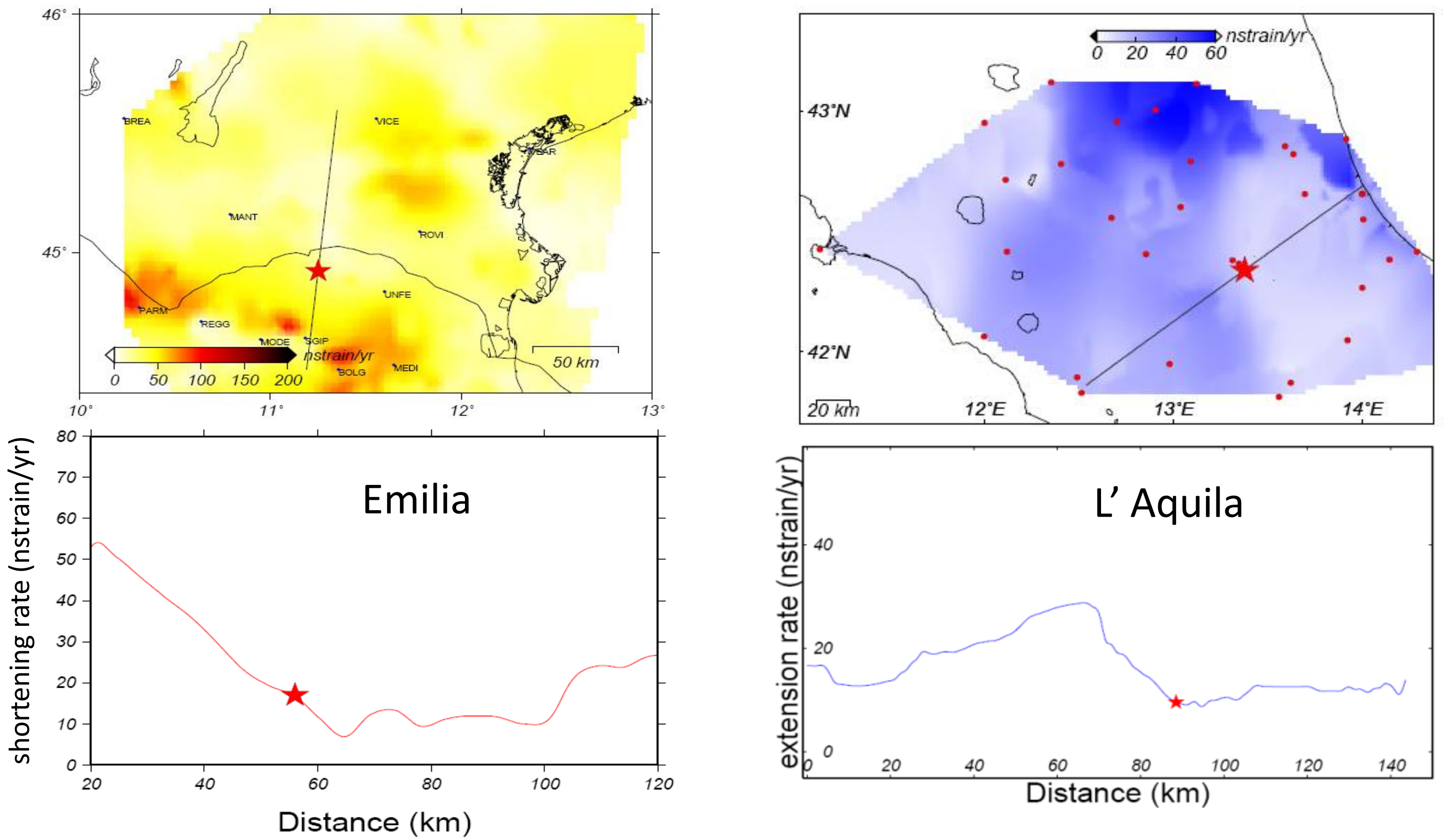
$$SR = \sqrt{(\dot{\varepsilon}_{11}^2 + \dot{\varepsilon}_{22}^2 + 2\dot{\varepsilon}_{12}^2)}$$





Riguzzi et al., 2012

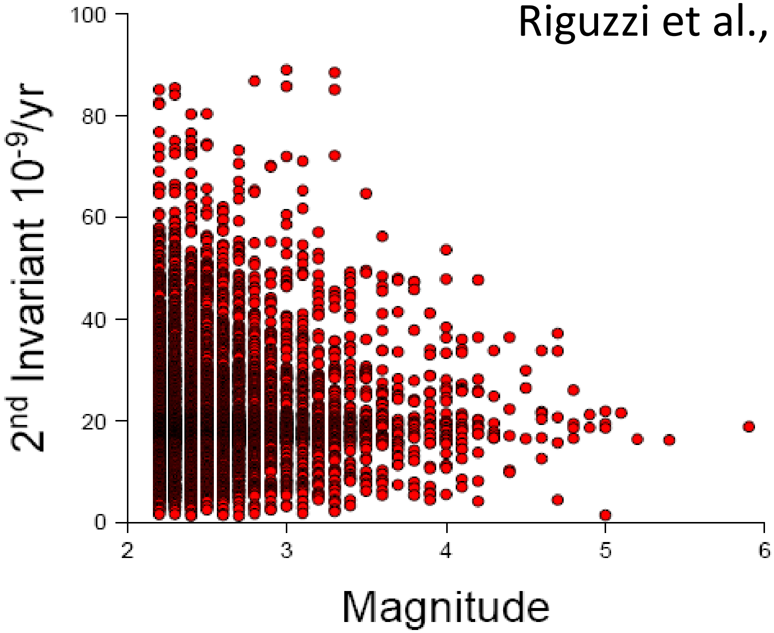
1c- Mapping the strain rate: snapshots of pre-seismic locked fault



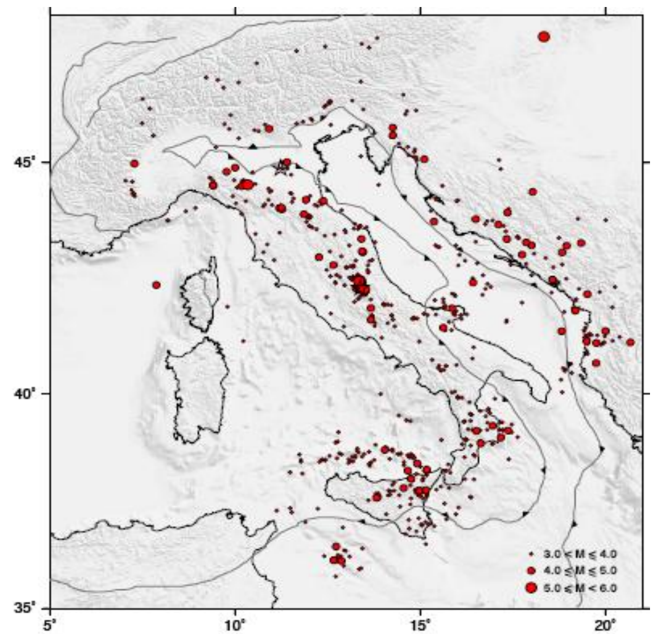
2a- Magnitude and strain rate

the size of seismic events appears inversely related to strain-rates

Eqs M≥2.2 from 2007 to 2011
Interpolation of the strain rate field at the epicenter coordinates



Riguzzi et al., 2012



2b- Magnitude and strain rate

Which is the occurrence probability of an earthquake of M in a given class of SR ?

analytical description based on a Bayesian approach

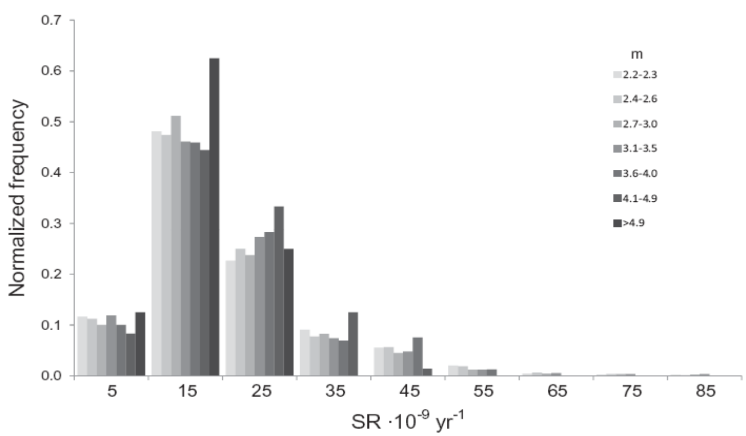
probability density of *M* occurrence from GR law

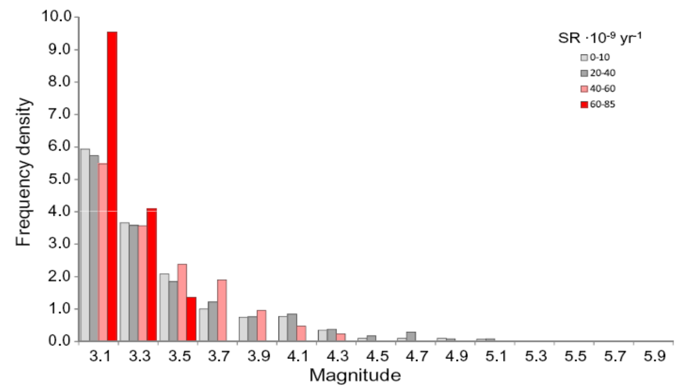
$$f(M|S) = \frac{f(S|M)\, f(M)}{\boxed{f(S)}}$$

probability density of *S* for each *M* class

normalization constant

$$f(S) = \int f(S|M) f(M)\, dM$$





Riguzzi et al., 2012

2c- Magnitude and strain rate

The probability density of *M*-occurrence in a given class of *S* is represented by a family of exponential-decay curves, calibrated by μ (normalized average *M)*

$$f(M|S) = \frac{1}{\mu(M|S)} \cdot e^{-\frac{M}{\mu(M|S)}}$$

Inversely to the interpretation of b-value, according to which a

high b-value $\Longleftrightarrow$ larger proportion of small events

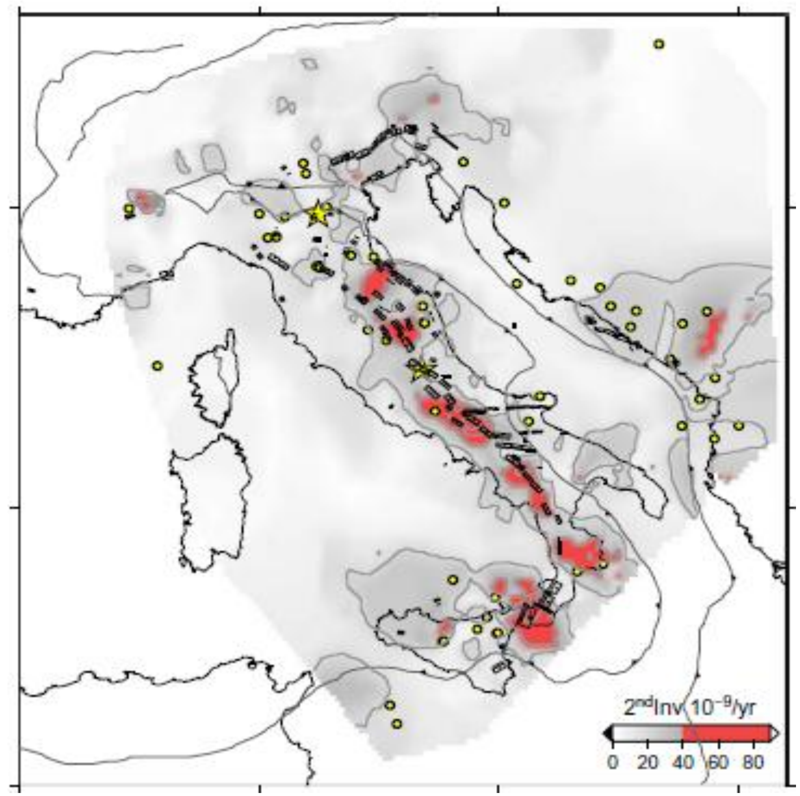
now

high μ-value $\Longleftrightarrow$ higher probability of large events

2d- Magnitude and strain rate

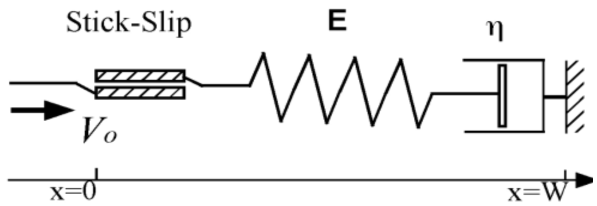
Example: the probability to have an earthquake with $M \geq 4.0$, the integral of $f(M|S)$ for $M \geq 4.0$) for each S class

- 0 –20 *nstrain* (μ = 0.14) is 9.1%
- 20–40 *nstrain* (μ = 0.15) is 10.3%
- 40–60 *nstrain* (μ = 0.13) is 7.6%
- 60–85 *nstrain* (μ = 0.06) is 0.5%

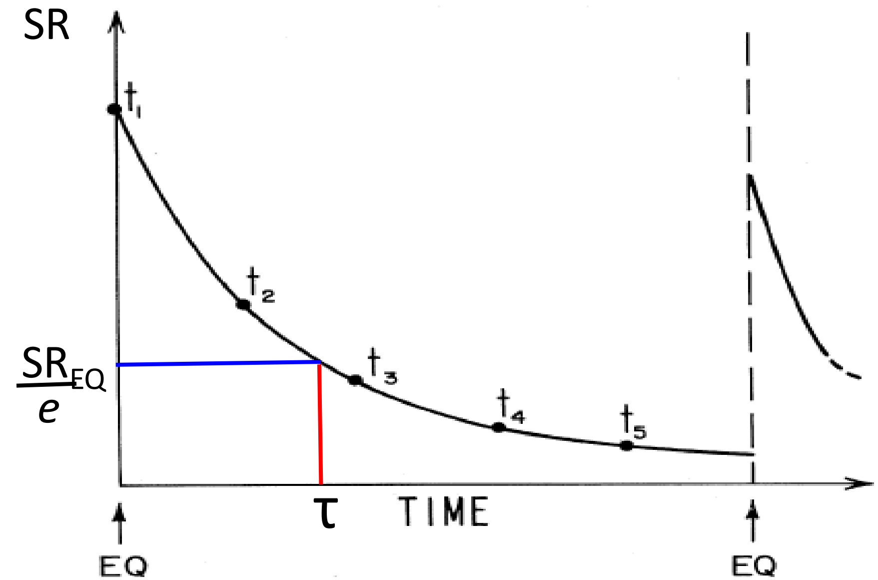


Riguzzi et al., 2012

3a- recurrence time ≥ relaxation time (?)



$\tau = 2\eta/\mu$



Model

- non-linear time evolution of strain rate due to visco-elastic properties of Earth
- classical process of time exponential decrease

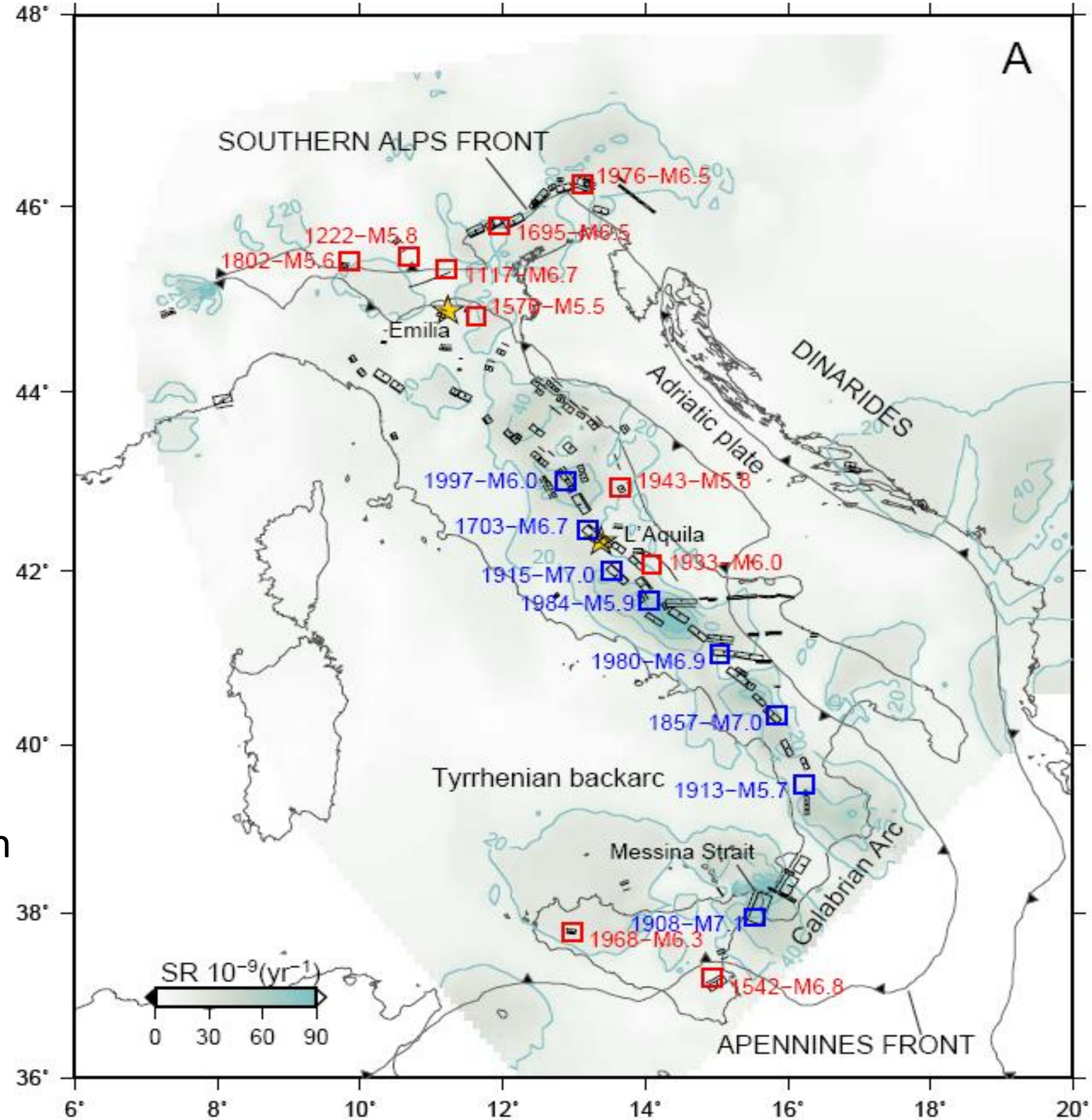
Assumptions

- the interseismic SR on different seismogenic sources of the same type behave as a stationary process: their time decaying rate are similar, dependent only on the time elapsed since the last strong earthquake

- the time decaying model parameters can be estimated just sampling the process on different seismogenic sources for which different intervals since the last strong earthquake elapsed

3b- timing the snapshots

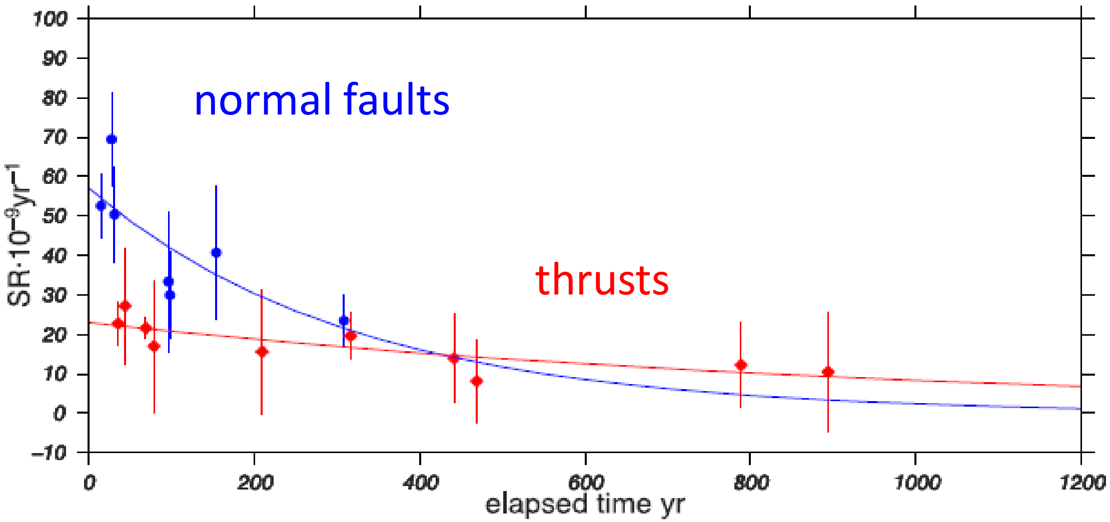
- SR map of the Italian area (contour lines every $20 \cdot 10^{-9}$ yr^{-1}) from the 2D velocity field
- individual seismogenetic sources reported in the DISS database (black boxes)
- the red (reverse faults) and blue (normal faults) boxes are the last significant seismic events reported in CPT04



Riguzzi et al., 2013

3c- timing the snapshots: fault relaxation time

Strain-Rate sampled at the epicentres of the selected events
vs.
elapsed time since the last event



Exponential decay models $SR(t) = a \cdot e^{-b \cdot t}$ with $\tau = b^{-1}$,
The characteristic times are $\tau_n = 317 \pm 204$ yr and $\tau_t = 991 \pm 690$ yr,
for normal faults and thrusts.
Therefore

$$\tau_t \sim 3 \cdot \tau_n$$

Riguzzi et al., 2013

Conclusions

MAPPING

Strain-Rate maps are **snapshots** of evolving deformations → **short term** occurrence studies

Strain-Rate **lows** within deforming areas → detection of **locked faults**

TIMING

Strain-Rate time relaxation at faults follows an exponential decay law

Relaxation and recurrence times of thrusts 3 times longer than normal faults

SIZING

Higher Strain-Rate corresponds to a lower probability of large size events